4. Results and Analysis

This section discusses the results for the six modeling alternatives as well as current and historical conditions for Yellowstone and Grand Teton. Two noise-related metrics were evaluated:

- Percent Time Audible (%TAUD) – The percentage of time that OSV sound levels are audible; and
- Time above A-weighted Sound Level (TALA) – The time in seconds that a given receiver point was above a specified A-weighted Sound Pressure Level.

The %TAUD contour maps are discussed in Section 4.1; the TALA distributions are discussed in Section 4.2; and the overall ranking of the alternatives is discussed in Section 4.3.

4.1. Contour Maps

The resultant INM percent time audible contour maps are shown in Appendix A. Sample percent time audible contours for Yellowstone are shown in Figure 23, Figure 24, and Figure 25 for Alternative 1A. Each color in the contour represents a different level of audibility. For example, the maroon contour indicates the area of the park that has audible events that occur not more than 10% of the time. In order to demonstrate the impact of peak and off-peak hours, contours presented in Figure 23 to Figure 25 and in Appendix E are for 1-hour time periods. Daily results are tabulated in Table 36 and Table 37 for Yellowstone and Table 38 and Table 39 for Grand Teton.

Based on the contours presented here, and in Appendix A, several general observations can be made about the modeling alternatives. 1) Events are generally audible within a relatively narrow corridor around the road segments. These corridors are typically between 3.5 and 5 miles wide. 2) Bends in the road segments increase the percent time audible in the area due to an increase in the exposure time as the vehicles traverse the curved region, see for example Figure 23. 3) The percent time audible reaches 100% near road segments with high numbers of hourly operations. For example, Alternative 1A has increased vehicle operations between 09:00 and 10:00 along the south entrance and west entrance roads due to visitors entering the park, resulting in 100% audibility along these roads during this hour. 4) When 100% audibility is reached the contour forms a plateau extending about 0.5 to 1.5 miles on either side of the road and then sharply drops to no audibility over a short distance. See for example the south entrance road in Figure 23. 5) Group size provides a potentially important tradeoff mechanism between park area and audibility. For example, in some areas of the park it may be desirable to increase the amount of time between successive OSV group events. This could be done in areas in which the concept of noise free intervals is important. By increasing group size, the noise free interval would effectively increase. The tradeoff is of course by increasing group size, the sound level associated with the group would increase and therefore the park area with “any audibility” would increase. Conversely, for areas of the park where 100% audibility has been reached, it may be beneficial to reduce group size. This would decrease the park area with “any audibility” but would not increase the percent time audible in the area nearest the corridor since it would already be at 100%. Further illustration of this tradeoff can be found in Appendix A.C.2.

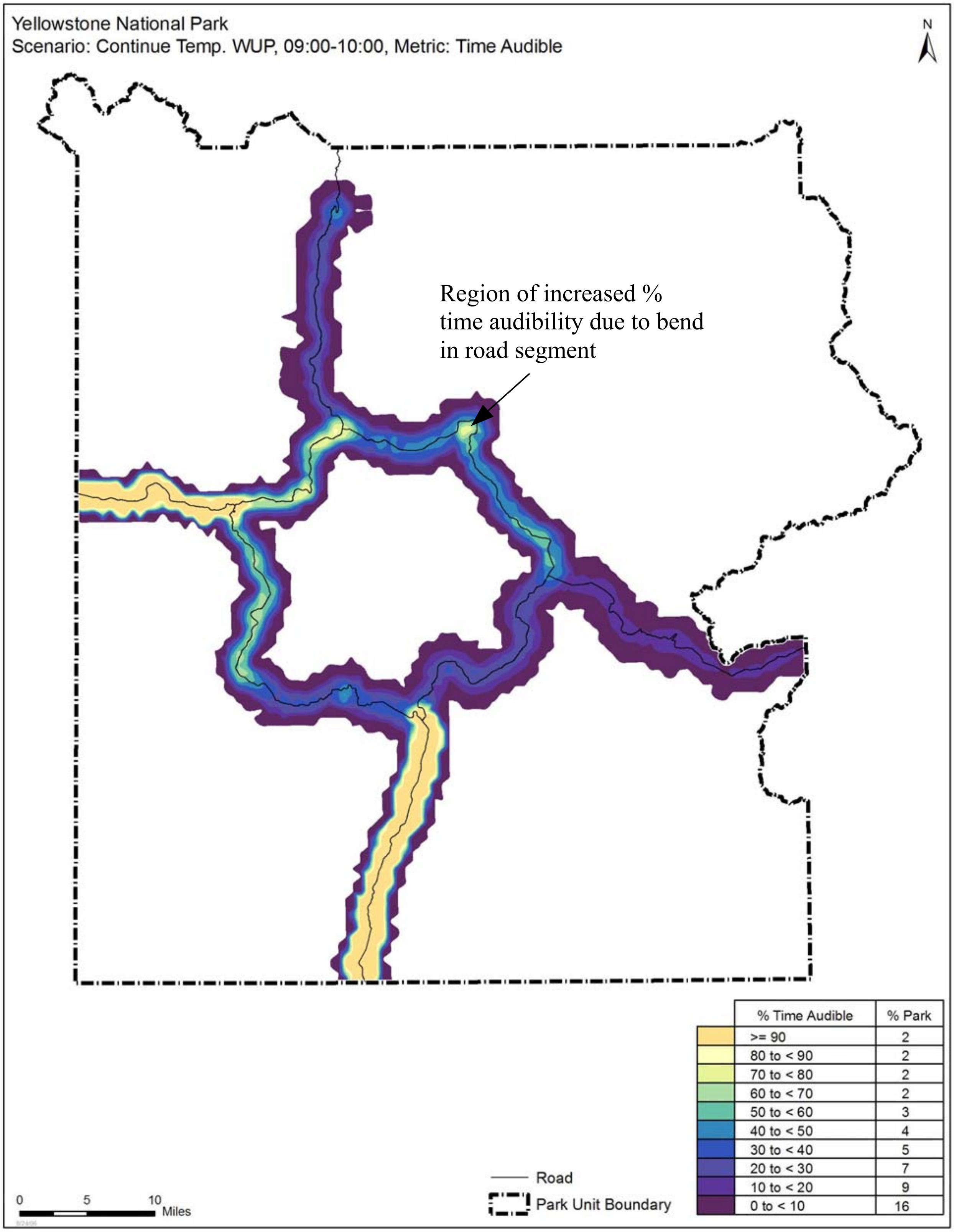
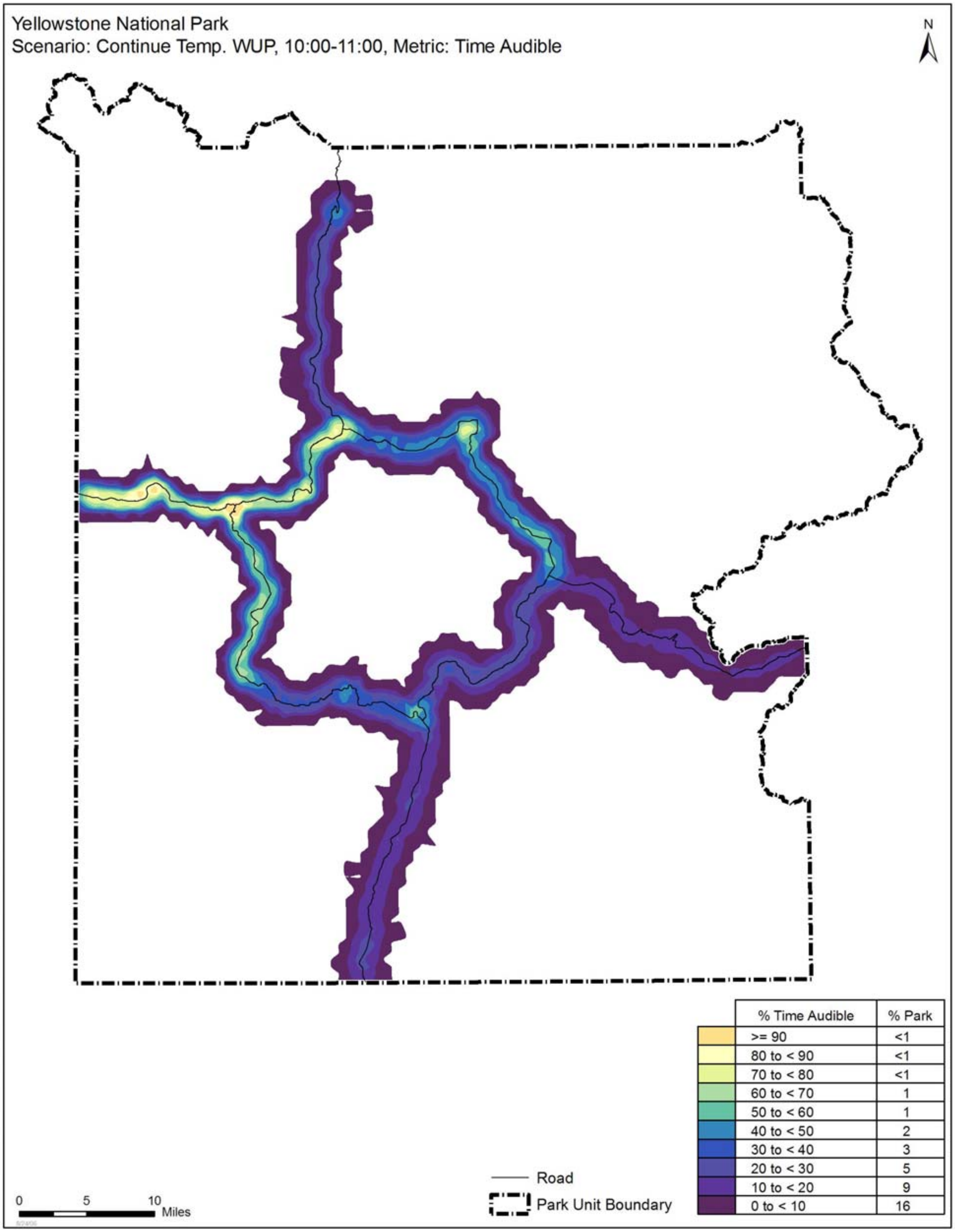


Figure 23: % time audible contour in Yellowstone for Alternative 1A, 09:00 to 10:00



% Time Audible	% Park
>= 90	<1
80 to < 90	<1
70 to < 80	<1
60 to < 70	1
50 to < 60	1
40 to < 50	2
30 to < 40	3
20 to < 30	5
10 to < 20	9
0 to < 10	16

Figure 24: % time audible contour in Yellowstone for Alternative 1A, 10:00 to 11:00

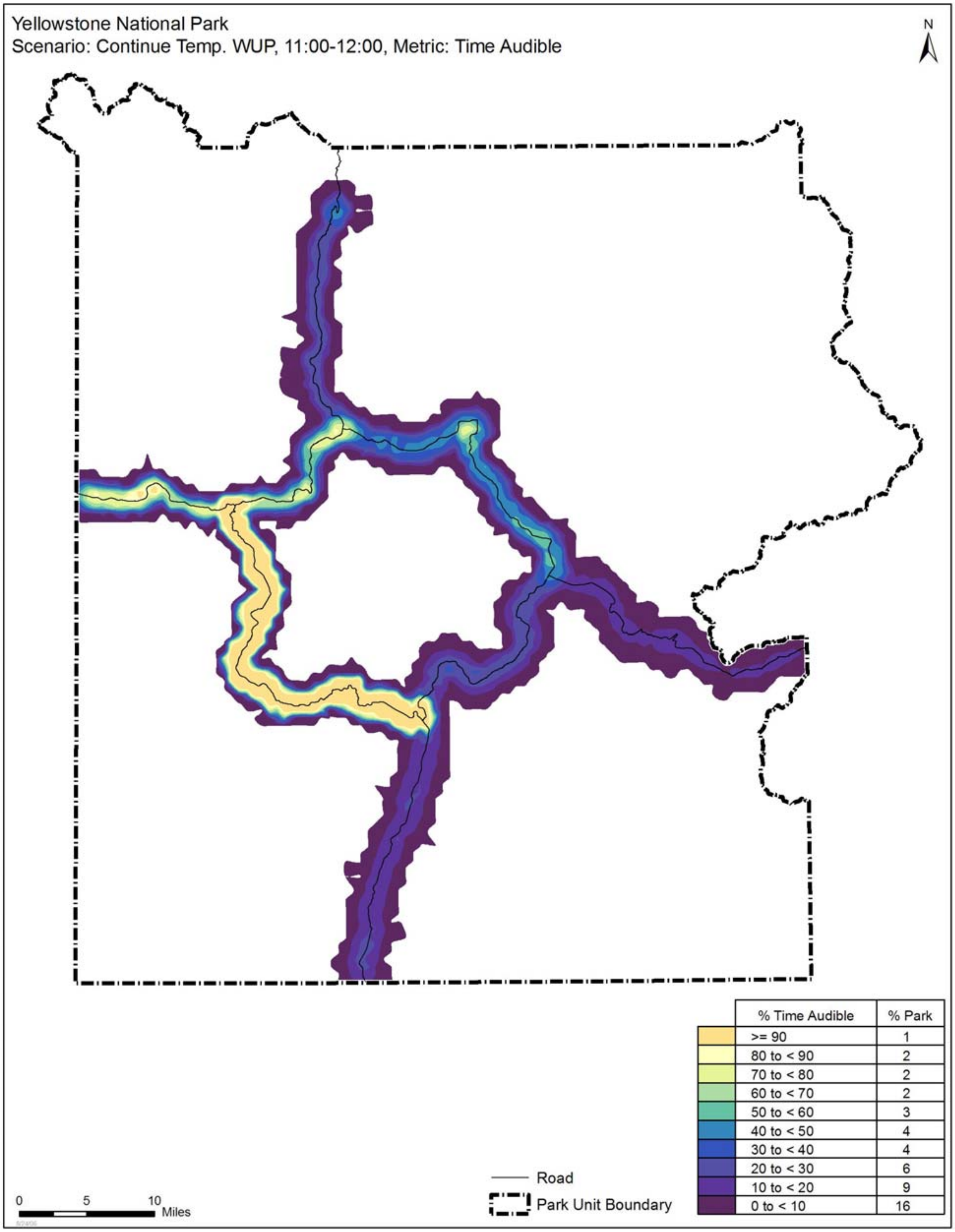


Figure 25: % time audible contour in Yellowstone for Alternative 1A, 11:00 to 12:00

4.2. Distributions based on Time Above A-weighted Level (TALA)

TALA was also calculated for sound levels starting at 0 dB(A) and increasing by 5 dB(A) until the level was not exceeded at any point during the given hour of operation. TALA was calculated for several locations that the Parks indicated were “points of interest”. These locations are shown in Figure 26 and Figure 27 for Yellowstone and Grand Teton respectively.

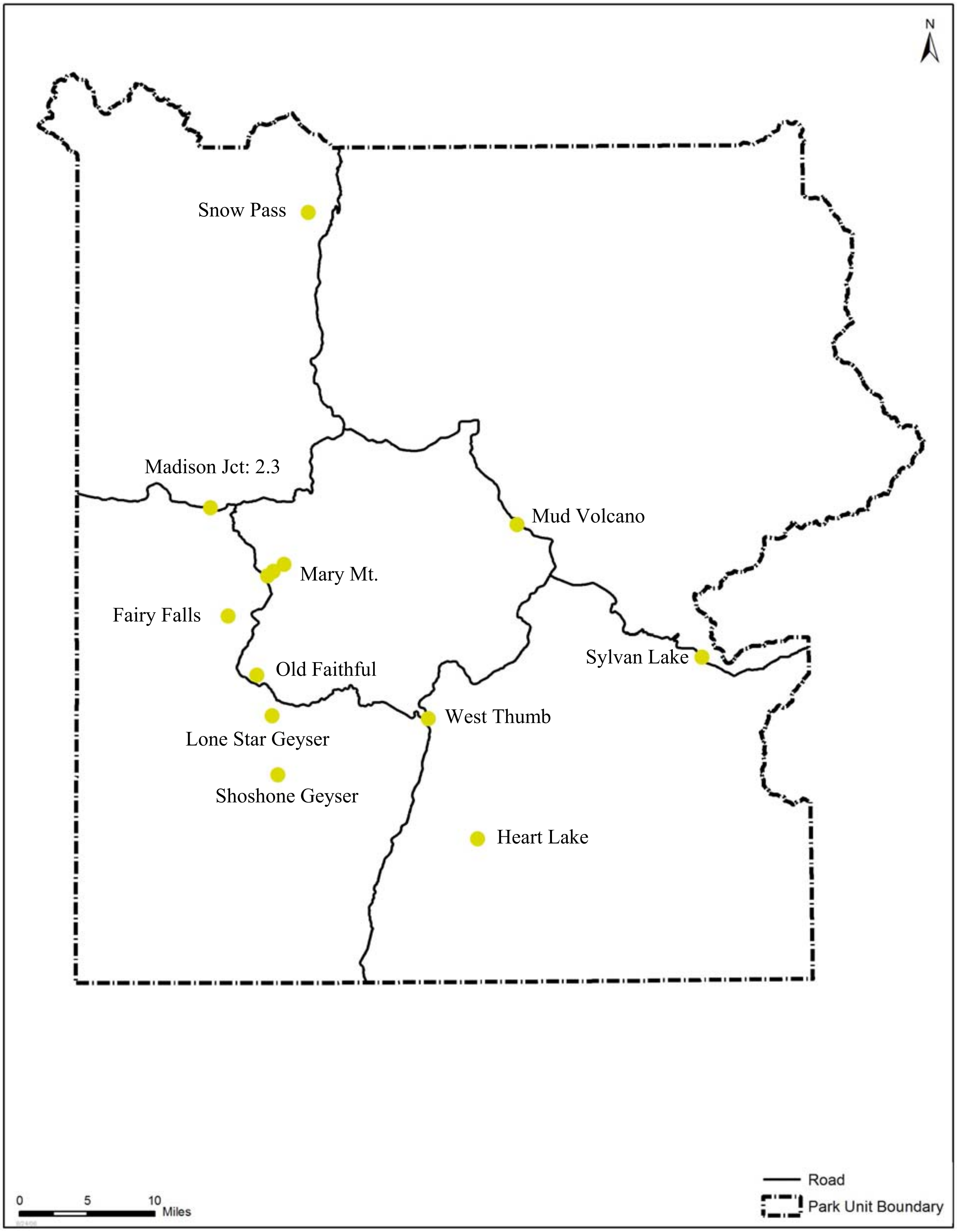


Figure 26: Location points in Yellowstone

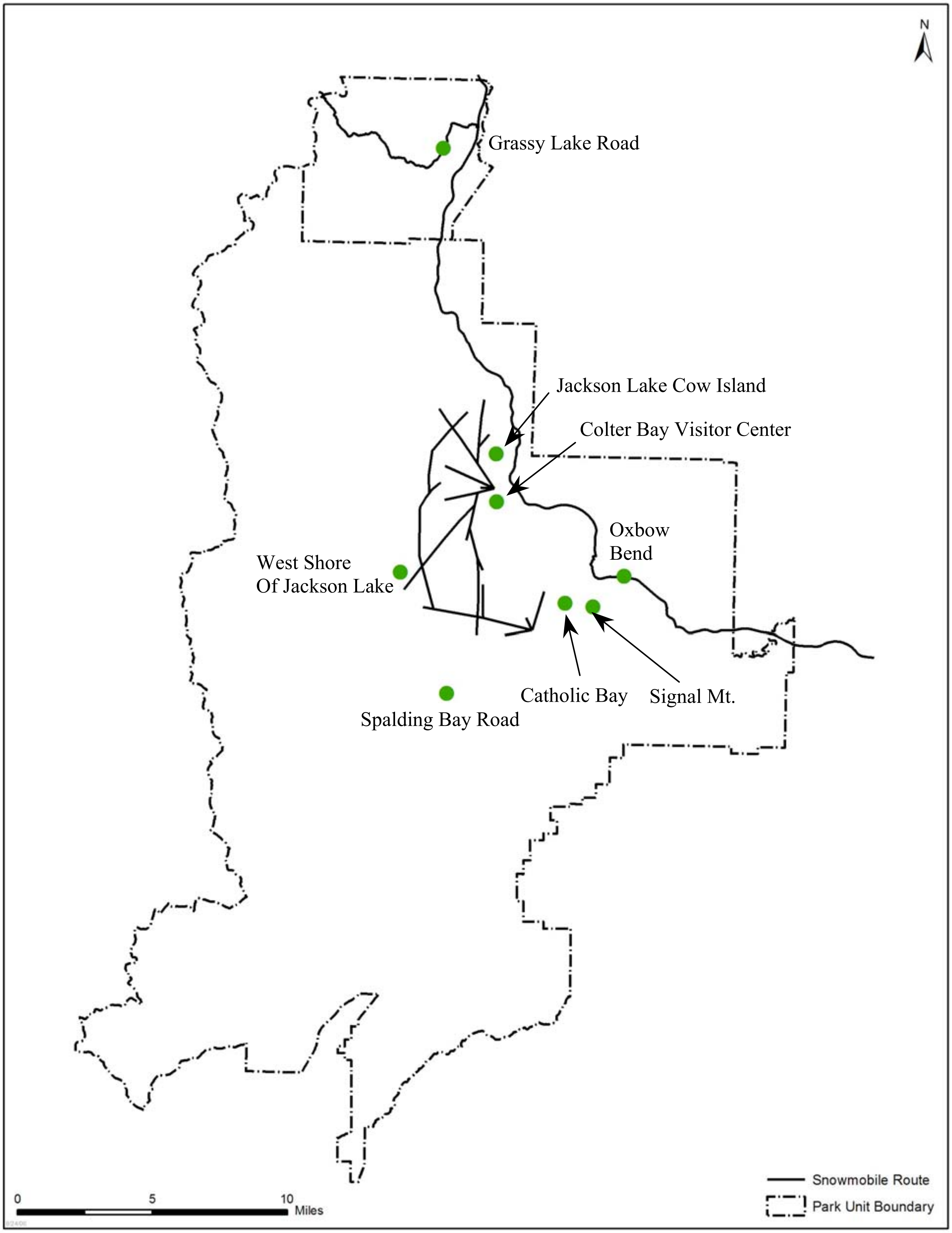


Figure 27: Location points in Grand Teton

Since TALA is a cumulative distribution, it always has the highest percentages at the lowest levels. This can be seen for the location point "Madison Junction: 2.3" in Figure 28 for Alternative 1A from 9:00 to 10:00 AM. It is sometimes instructive to show the time that the sound level is *between* two levels. This is equivalent to the difference between corresponding TALAs as given by,

$$\Delta TALA_{i\text{-}j} = TALA_i - TALA_j,$$

where i is the A-weighted sound pressure level for the lower end of the range and j is the A-weighted sound pressure level for the upper end of the range. These results will be referred to as ΔTALA. The distribution for ΔTALA for location point "Madison Junction: 2.3" is shown in Figure 29 for Alternative 1A from 9:00 to 10:00 AM. Note that in this case the lowest levels do not have the highest times. This is because 100% of the time has been allocated within the bands from 20 to 50 dB(A). Allocating additional time to other ranges would result in a time greater than one-hour for this one-hour interval.

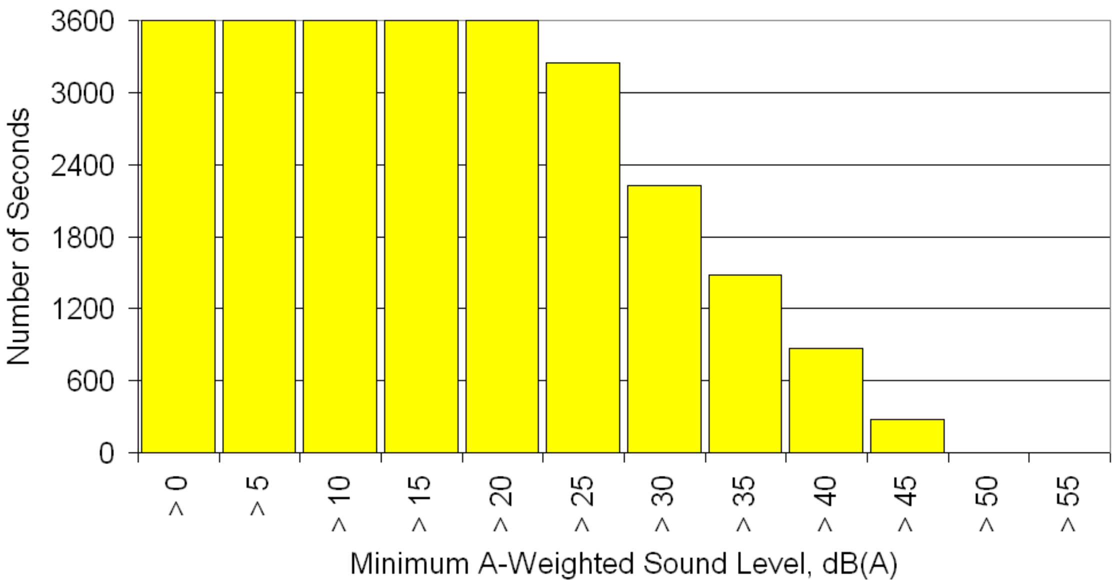


Figure 28: TALA at location point "Madison Junction: 2.3" location for Alternative 1A during the 9:00 to 10:00 hour

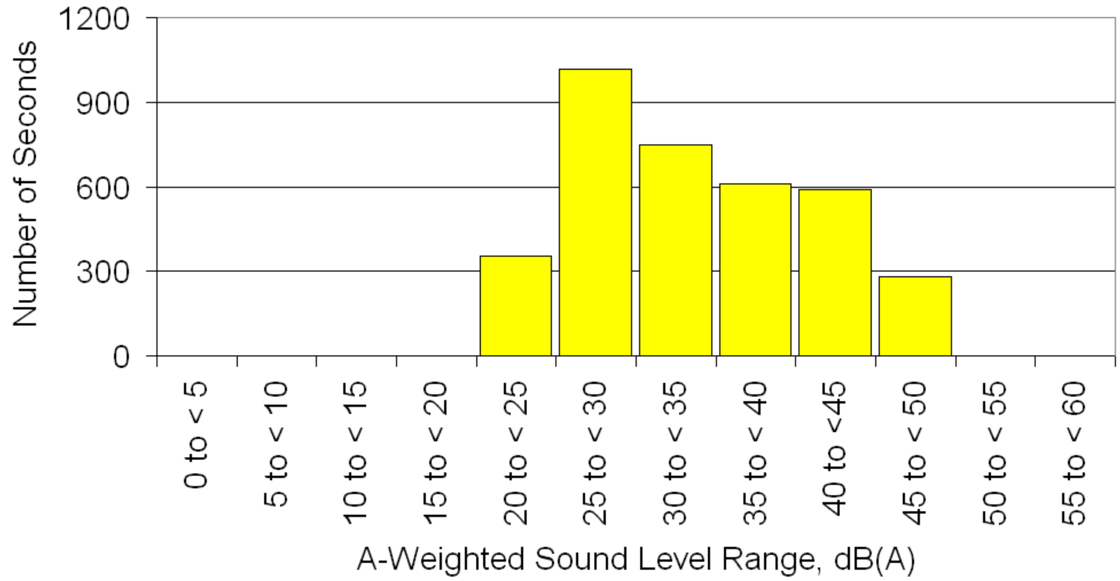


Figure 29: ΔTALA at location point "Madison Junction: 2.3" location for Alternative 1A during the 9:00 to 10:00 hour

Sample results for ΔTALA are shown in Table 12 for Alternative 1A during the 10:00 to 11:00 AM. Each row contains the results for a different location point. Each column is a 5 dB(A) range. The entry in the table indicates the number of seconds for the 1 hour period that the sound was within the specified 5 dB(A) range. For this modeling alternative / hour, Location points "Heart Lake" and "Shoshone Geyser" had no sound levels greater than 0 dB(A), while "Madison Junction: 2.3" had the highest sound levels. These results are typical since "Heart Lake" and "Shoshone Geyser" are far from the travel corridor while "Madison Junction: 2.3" is adjacent to the corridor. Results for all alternatives and hours are included in Appendix F. In many cases the indicated sound levels are below ambient for a given location. This however does not indicate that there are no audible events. Audibility generally depends on a single component having a sufficient signal-to-noise ratio[a] (SNR). That is, audibility can occur even when the overall level is below the ambient[26].

[a] where the signal level is determined by the source and the noise level is determined by the ambient and auditory system noise

Table 12: ΔTALA, in seconds, at Locations in Yellowstone, Alternative 1A, 10:00 to 11:00

Number of seconds in dB Range	0 to < 5	5 to < 10	10 to < 15	15 to < 20	20 to < 25	25 to < 30	30 to < 35	35 to < 40	40 to <45	45 to < 50	50 to < 55	55 to < 60
Fairy Falls	166	32	0	0	0	0	0	0	0	0	0	0
Heart Lake	0	0	0	0	0	0	0	0	0	0	0	0
Lone Star Geyser	310	288	126	4	0	0	0	0	0	0	0	0
Madison Jct. 2.3	774	810	569	414	313	223	169	133	133	61	0	0
Mary Mt. 4000'	842	576	317	79	0	0	0	0	0	0	0	0
Mary Mt. 8000'	515	90	0	0	0	0	0	0	0	0	0	0
Mary Mt. Trailhead	806	500	346	274	270	119	4	0	0	0	0	0
Mud Volcano	641	464	356	288	230	176	47	0	0	0	0	0
Old Faithful	1253	778	580	306	7	0	0	0	0	0	0	0
Shoshone Geyser	0	0	0	0	0	0	0	0	0	0	0	0
Snow Pass	108	0	0	0	0	0	0	0	0	0	0	0
Sylvan Lake	180	137	104	68	50	36	25	22	14	14	11	0
West Thumb	745	569	407	288	184	86	36	0	0	0	0	0

When ΔTALA is analyzed hourly, the pattern is strongly affected by the number of operations near the location point. Overall, peaks in the hourly distributions correspond to hours that have peak operations on nearby road segments, thus peaks in the hourly distributions are consistent with high percent time audible results found in the contours, see for example Figure 23 to Figure 24.

Table 13: Hourly ΔTALA, in seconds for a given sound level range in dB(A). The location is Madison Junction: 2.3. The alternative is 1A.

Hour of Operation	0 to < 5	5 to < 10	10 to < 15	15 to < 20	20 to < 25	25 to < 30	30 to < 35	35 to < 40	40 to <45	45 to < 50	50 to < 55	55 to < 60
08:00 to 09:00	774	810	569	414	313	223	169	133	133	61	0	0
09:00 to 10:00	0	0	0	0	353	1019	749	608	590	281	0	0
10:00 to 11:00	774	810	569	414	313	223	169	133	133	61	0	0
11:00 to 12:00	760	824	763	220	313	223	169	133	133	61	0	0
12:00 to 13:00	760	824	763	220	313	223	169	133	133	61	0	0
13:00 to 14:00	760	824	763	220	313	223	169	133	133	61	0	0
14:00 to 15:00	774	810	569	414	313	223	169	133	133	61	0	0
15:00 to 16:00	0	0	0	0	353	1019	749	608	590	281	0	0

4.3. Ranking Modeling Scenarios

To summarize the results, the modeling alternatives were rank-ordered based on the percent of the park affected by 0 and 50% time audible for Yellowstone and by 0% time audible for Grand Teton[a]. The rank orders for any non-zero percent time audible, i.e. at least one audible event, are shown for Yellowstone in Figure 30 and for Grand Teton in Figure 32. From this point on, this will be referred to as "any audibility". The rank orders for greater than 50 percent time audible are shown for Yellowstone in Figure 31. The park percentages are obtained from the contour

[a] Grand Teton did not have Alternatives with audible events 50% of the time so that ranking was not done for Grand Teton. Lower % time audible levels were examined, but the only significant effect was that for higher % time audible, the Current Conditions had the lowest rank due to its small number of operations.

plots in Appendix E by reading off the value in the "% Park" column of the map contours for the desired "% Time Audible".

4.3.1. Yellowstone Ranking

The graph in Figure 30 shows the percent of Yellowstone, which has "any audibility" during the entire 8-hour day. (The park area affected by a given percent time audible range for the entire day was determined by averaging the park area affected by a given percent time audible range for all hours.) In order to understand the rankings, it is constructive to consider some of the significant factors for each alternative. It can be seen that Alternative 3 has the lowest park area affected for "any audibility". This is quite reasonable, since this alternative included the closure of most road segments. Alternative 2 also has a relatively low audibility due to the exclusion of snowmobiles and the use of only BAT snowcoaches. Alternative 6 included the closure of the outer eastern portion of the east entrance road[a] and additionally included plowing of the west side of the park to allow wheeled vehicles rather than OSVs. (Wheeled vehicles have lower sound levels than do OSVs so audibility is reduced.) Alternatives 1B and 1D have lower audibility than 1A for the most part because in 1B and 1D the east entrance is closed, but for 1A it is open. Additionally, Alternative 1A included groups as large as 17 vehicles, the added vehicles increased the source level and thus the audible distance. Alternatives 5 and 4 both had the east entrance open, similar to Alternative 1A, however, some of their groups were smaller, 5 per group, resulting in lower source levels for some pass-by events, thus shortening the distance. The Current Condition did not have a BAT restriction on snowcoaches. This means that the vehicles with the highest sound levels of all modeled vehicles were included. Finally, the Historical Condition had the highest audibility because it includes the use of all road segments with no closures and it includes both BAT and non-BAT snowmobiles and snowcoaches.

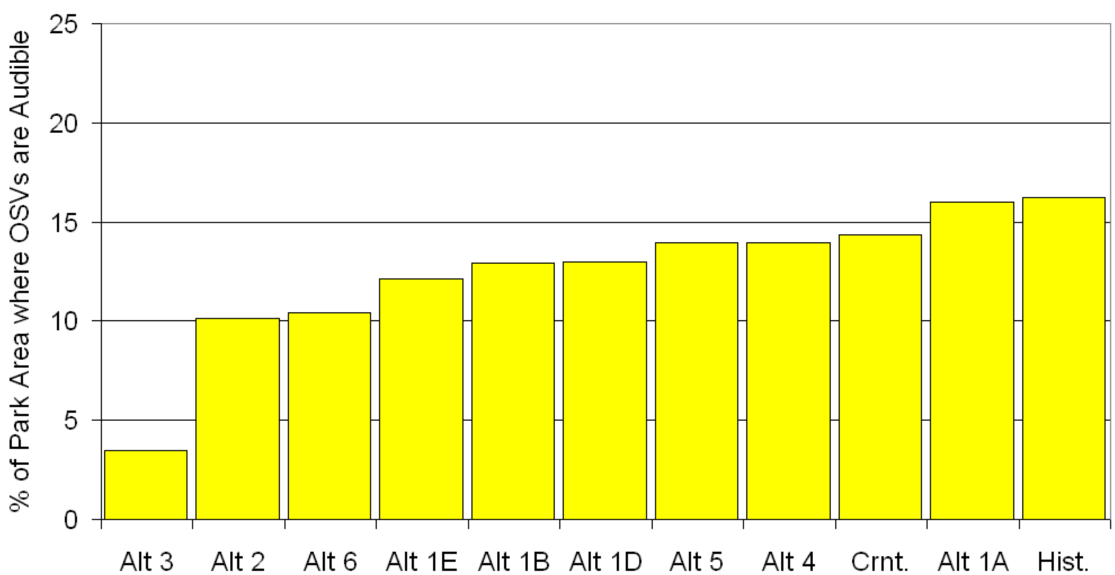


Figure 30: Percent of Yellowstone with any level of OSV audibility

[a] The road segment from Fishing Bridge to Lake Butte should include some vehicle operations, but these were not provided by the Parks. Audibility will not increase significantly due to a small number of operations along this short road segment. Therefore this alternative will not be remodeled for the time being.

Whereas the case for "any audibility" represents the case where even a single event is heard and thus is strongly affected by source level and road segments open, the case for 50% audibility also includes a sensitivity to the number of operations that are audible. In Figure, the most significant effect of considering the 50% audibility case is that those alternatives with increased operations, namely Alternative 4 and the Historical Condition affect significantly larger park areas, while the audibility of the Current Condition, which has relatively low numbers of operations, moves down relative to the "any audibility" case. Overall, considering the case for both "any audibility" and the case for 50% audibility all modeling alternatives affect smaller park areas than does the Historical Condition for Yellowstone.

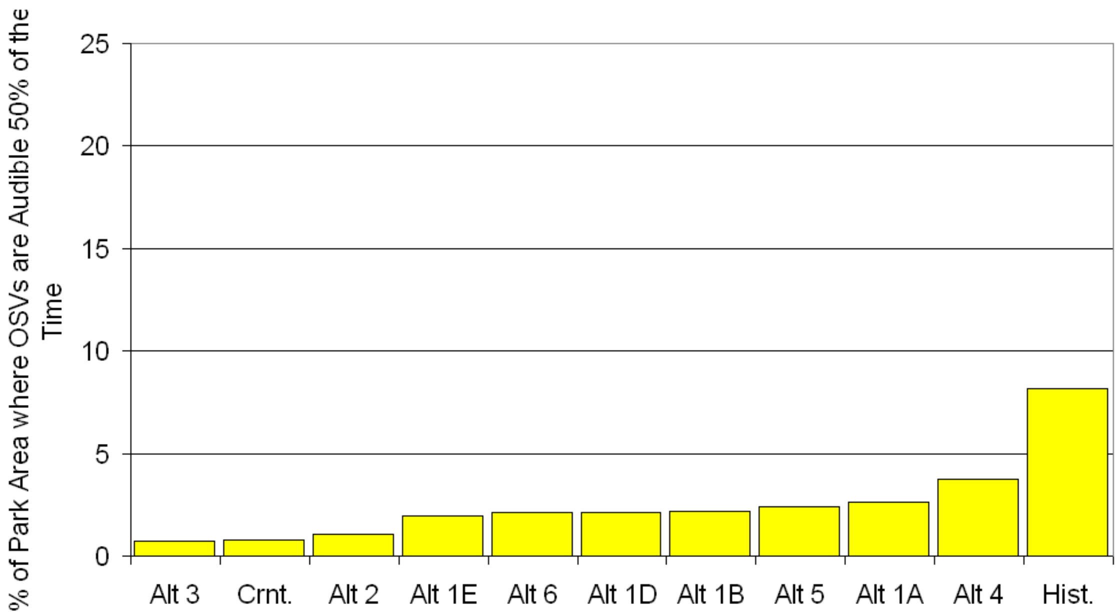


Figure 31: Percent of Yellowstone with 50% OSV audibility

4.3.2. Grand Teton Ranking

Figure 32 shows the percent of Grand Teton, which has "any audibility" over the entire 8-hour day. As with Yellowstone, a quick summary of significant factors is constructive. Because many of the alternatives in Grand Teton involved closing portions of the travel area (either the Grassy Lake road, the CDST, or Jackson Lake), the areas open to snowmobile use are a significant factor. Alternative 2 did not allow any snowmobile use in Grand Teton, thus it is not considered in this analysis. Alternative 3 had only the Grassy Lake road open to use so it is reasonable that it has the smallest park area affected. Both the Current Condition and Alternative 6 do not model travel along the CDST[a]. This is a long road, and its exclusion significantly reduces the park area affected by audible events. The four alternatives with highest audibility included use on all three travel areas in Grand Teton (Grassy Lake Road, The CDST, and Jackson Lake). Of the four, the Historical Condition has the lowest audibility because it was modeled using two-stroke snowmobiles. Although two-strokes have higher source levels according to the spectral data available (see Figure 41 and Figure 42 in Appendix C.1), they have more acoustical energy in the higher frequencies, thus their sound levels attenuate more quickly

[a] For Alternative 6, travel along the CDST is prohibited. For the Current Condition, travel is very close to zero.

through the atmosphere. Alternatives 1 and 5 had very similar operations to the Historical Condition, but having four-stroke snowmobiles, they affected a slightly larger area than did the Historical Condition. Finally Alternative 4 had the highest audibility due in part to the inclusion of larger group sizes, 11 per group and therefore higher sound source levels, along the CDST.

The percent TAUD was generally below 20%. Because of these lower percentages, an analysis of 50% time audible was not conducted for Grand Teton.

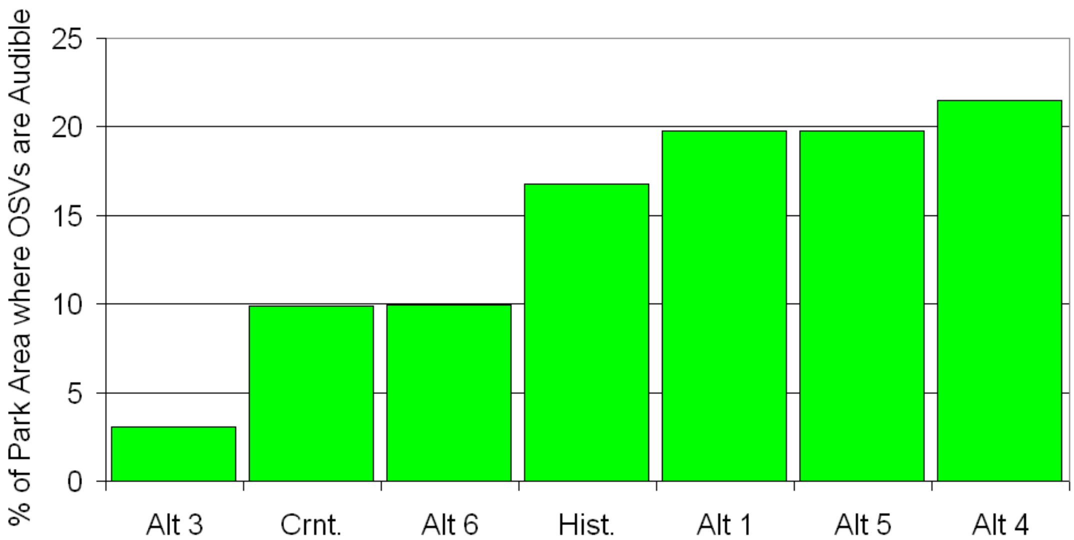


Figure 32: Percent of Grand Teton with any level of OSV audibility

5. Conclusions and Recommendations

A modified version of the FAA's INM Version 6.2 was developed to model the sound from OSVs in Yellowstone and Grand Teton National Parks. Modifications to the INM include new spectral classes and modified Noise-Power-Distance curves (Noise-Speed-Distance curves) for two- and four-stroke snowmobiles and three types of snowcoaches. Snowmobiles were modeled as operating in groups by combining the levels of all vehicles in the group into a single source (see Section 3.2.3 and Appendix A.C.2). In addition, the ground-to-ground propagation in INM was updated to be more representative of propagation over snow-covered terrain using the basic acoustic theory in the FHWA's TNM (see Appendix A).

The parks have been organized into two primary acoustic zones, open and forested, with natural ambient backgrounds provided by NPS for each acoustic zone. An additional zone, human development, has also been defined but has not yet been assigned its own unique ambient sound level (see discussion in Section 3.1.4). OSV paths were modeled along Yellowstone and Grand Teton roadways and on Jackson Lake in Grand Teton. Six NPS-designed modeling alternatives as well as current and historical conditions were studied. Each modeling alternative was evaluated for an 8-hour day with temperature, relative humidity, and snow cover representative of an average day during the winter season in the parks. In order to account for increased usage during peak hours, the 8-hour day was divided into 1-hour intervals and vehicle operations were assigned based on scheduling provided by the National Park Service. Results include contours for each alternative showing percent time audible (%TAUD) as well as tabulated time in seconds above specified A-weighted levels (TALA).

Percent time audible (%TAUD) contours and time in seconds above A-weighted level (TALA) were calculated for the modeling alternatives, as well as for current and historical conditions. The percent time audible contours had highest levels near the OSV travel corridors. Increases in operations increased the highest percent time audible up to a maximum of 100%. Increases in group size and the inclusion of snowcoaches that do not meet Best Available Technology (BAT) specifications increased the park area with "any audibility". Although not intuitive, inclusion of snowmobiles that do not meet BAT specifications did not increase the park area with "any audibility". Although these results were initially thought to be erroneous, further investigation indicated them to be correct and to be a result of the spectra associated with BAT and non-BAT snowmobiles. Specifically, the sound levels from non-BAT snowmobiles attenuated faster with increasing distance than the sound levels from BAT snowmobiles, which had greater sound energy at low frequencies. However, non-BAT snowmobile sound levels near the travel corridor were higher than BAT snowmobiles. Similar trends were found from the results of the TALA calculations.

The following additional work is recommended:

- Collect additional source data.
    - Include a greater range of vehicles and speeds to better represent the Park's OSV fleet. Include a greater range of vehicles and speeds to better represent the Park's OSV fleet. This should include any vehicles that make up a significant portion of the operations to be modeled, especially if no vehicles with similar acoustic characteristics have already been included.

    - Include a greater number of repetitions to provide more statistical confidence in the mean levels.
- Run controlled operations for validation, e.g. measure L_{Amax} for a single snowmobile at several locations simultaneously.
- Run modeling alternatives for cold and warm days and humid and dry days to determine sensitivity to weather extremes.
- Run alternatives for different types of snow cover, e.g., freshly fallen snow versus ice. This will require further modeling of ground effects.
- Use park fleet distributions to weight source data for each vehicle model when estimating the mean level for each source type. For example if there are 200 Snowbuster snowcoaches and 100 Bombardier snowcoaches in the park fleet, then the Snowbusters could be counted twice and the Bombardiers could be counted once when averaging source levels.
- Conduct surveys to determine visitor responses to alternatives that can be modeled. Averaged response ratings could be correlated to acoustic metrics such as percent time audible. This would provide an understanding of what metric levels are acceptable to park visitors.

It is understood that these tasks represent a large investment of several groups' time and resources. Further discussion needs to be conducted in order to prioritize these and to determine which items are actionable.